# Effects of Australian rice farming systems on soil organic carbon concentrations

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**Abstract**
Considering a shift from pasture based conservative rice farming to intensive rice cultivation in rotations with winter and/or summer crops (wheat, barley, oats, soybeans, sorghum, and corn), an investigation was conducted during 1999-2006 to benchmark different rice paddocks for monitoring changes in soil organic carbon (SOC) and other important properties. Composite samples were collected from the surface (0-10 cm) and sub-surface (10-30 cm) layers of 250 commercial rice paddocks and 50 experimental plots. Sampling sites were GPS marked for future use. Analysis of appropriately processed soil samples was done for SOC, $EC_{1:5}$, $pH_{1:5}$ (0.01M $CaCl_2$), and CEC. Another investigation was also conducted to compare the effects of two native land uses (grassland, and treeland) with cultivated soils. Analytical results indicated a gradual decrease in SOC with increased rice cropping intensity. Surface layer of red brown earth (RBE) paddocks showed comparatively lower SOC and pH than its transitional red brown earth (TRBE) and grey (Grey) soil counterparts. This was also true for the effects of the native land uses. Regardless of soils, sampled rice paddocks were non-saline for both depths. Surface layer CEC of grey soil paddocks was significantly more than those of the TRBE and the RBE paddocks. However, this variation was less in deeper layers.

**Key Words**
Rice soils, soil fertility and productivity, soil analysis, soil changes, farming practices, rice cropping.

## Introduction
Commercial cultivation of rice in Australia commenced in late 1920s. Since then the area under rice has increased gradually with the development of irrigation in semi-arid areas of Murrumbidgee and Murray valleys of south western NSW, notwithstanding fluctuations due to the available irrigation water each year and recent droughts. In early decades, irrigated pastures (*Trifolium subterraneum*) based rice was the predominant farming system. Irrigated pastures helped improve nitrogen fertility of the common rice soils (Williams and Raupach 1983), most of which were inherently fragile and had low productive potential. Advent of high yielding fertiliser responsive rice varieties during the late 1960s, however, boosted rice productivity tremendously and caused notable diversification and intensification of the Australian rice farming systems.

Comparatively high profitability of the Australian rice farming systems depends upon their relatively high yields (9-10 t/ha unhusked rice). Application of 180-200 kg N/ha to rice grown in non-pasture cropping systems is now a common practice (Gill 2009). This implies that appropriate management and monitoring of rice soils for their fertility and productivity is necessary to sustain high grain yields. Different viewpoints (Karlen *et al.* 1997; Dalal *et al.* 2003) on quality and health of desirable soil conditions for highly productive land uses indicate that maintenance of optimum soil organic matter (SOM) concentrations in rice soils is of paramount importance because of its role as a store house for supplying native soil N, which accounts for approximately half of total N uptake of rice crops. In addition, SOM causes significant chemical, biological and physical effects on other beneficial soil functions. Available research information related to the impact of predominant Australian rice farming systems on SOC is limited and not quantitative. An investigation was, thus, carried out to benchmark and monitor periodically selected rice paddocks to ascertain changes in SOC of major rice soils due to the common rice farming systems.

## Methods
This paper is based on investigations carried out during 1999-2006. We aimed at having quantitative assessment of the current status and benchmarking sites for monitoring temporal changes in total organic carbon content of the soils typical to the common Australian rice farming systems. A parallel study was also conducted to compare total organic carbon concentrations of soils common to rice farming systems and the two native land uses (grasslands, and treeland).

*Site selection*
Study sites were selected based on a written survey and interviews with numerous farmers. More than 282 paddocks and 50 experimental plots were chosen across the major rice growing districts of Murray and Murrumbidgee valleys considering information collected on each paddock such as the differences in rice cultivation intensity, three soil types [(grey Vertosols, red brown earth Chromosols (RBE), and mixture of these two called transitional red brown earths (TRBE)] typical of most rice paddocks, short and long term history of rice farming systems, fertilizer use, water use, average rice productivity, rice varieties grown, management practices, use of rice check, soil and plant analysis (panicle initiation NIR test) for diagnosing crop needs for fertilizers etc. Similarly, 96 sites were selected comprising the two native land uses (grass land, and treeland) and the surrounding cultivated soils across the major rice growing areas and districts.

*Soil sampling*
Using a mechanical corer, surface (0-10 cm) and sub-surface (10-30 cm) soil samples were collected from each of the selected paddocks before their fertilization for growing rice. Each sample was a composite of 20 cores taken randomly from different locations within each rice paddock. All of the 20 locations in each rice paddock were marked with GPS for future monitoring. Each sample was air dried at 40$^{o}$C before processing (grinding, sieving) and stored in large polythene bottles. Similar procedure was used for sampling from the grassland and the treeland sites without GPS markings. However, the soil at each location was sampled to 50 cm depth in five equal layers of 10 cm. Sampling was done with soil augers due to accessibility problems. Composite samples for each of the five depths were prepared by mixing ten samples from each location.

*Soil analysis*
Appropriately processed soil samples were analyzed for soil acidity by measuring pH of soil in 0.01M $CaCl_2$ solution and soil salinity by determining EC of soil in de-ionized water using 1:5 soil-solution ratios (w/v) following procedures of Rayment and Higginson (1992). Total soil organic C and N were determined by the dry combustion using LECO CNS-2000 Analyzer. The cation exchange capacity (CEC) was determined following the method of Anderson and Ingram (1993).

*Statistical analysis*
Variation in different soil properties due to the given land uses, rice farming systems, soil types and depths were analyzed using analysis of variance, considering land uses, soil types, farming systems, and depths as definite variables but sites as random variables.

## Results
Data on average SOC concentrations in various layers of the three soils indicate (Table 1) significant differences due to their land uses. Regardless of the soil types and their land uses, maximum accumulation of SOC was found to occur in the surface (0-10 cm) layer. Average SOC concentrations due to the treeland use were considerably higher in layers between 0-30 cm depths as compared to the other two land uses. This is attributed to the minimum soil disturbance, regular additions of litter materials to the surface soil, and conservative effects of tree canopies associated with beneficial modifications in micro-climate for protecting soil organic materials from decomposition.

For each of the three land uses, SOC averages of the Grey and the TRBE were significantly greater than the RBE for 0-10 cm and 10-20 cm depths. Experimental results (Table 1) also demonstrate beneficial influence of irrigated cropping in building SOM up. A comparison between irrigated cropping and grassland shows that the former was effective in increasing SOC more than the latter. This effect was especially pronounced in 0-10 cm layer. For example, SOC means of 1.75, 1.70, and 1.44 g/100g soil for the Grey, TRBE, and RBE under irrigated cropping were significantly greater than their corresponding averages of 1.45, 1.12, and 1.33 g/100g soil under grassland use, respectively.

**Table 1. Mean SOC concentrations (g/100g) in different layers of the three soil types under the three given land uses. (Significance of differences between soil types under different land uses using Tukey's post-hoc test indicate that means with different letters are significantly different at P=0.05).**

| Soil layer | Irrigated cropping | | | Treeland | | | Grassland | | |
|---|---|---|---|---|---|---|---|---|---|
| (cm) | Grey | RBE | TRBE | Grey | RBE | TRBE | Grey | RBE | TRBE |
| 0-10 | 1.75a | 1.44b | 1.70a | 3.46a | 2.45b | 2.95c | 1.45a | 1.12b | 1.33c |
| 10-20 | 1.65a | 1.32b | 1.52c | 2.92a | 1.88b | 1.82b | 1.28a | 0.96b | 1.15c |
| 20-30 | 1.41a | 1.13b | 1.35c | 1.81a | 1.55b | 1.73a | 0.86a | 0.74a | 0.78a |
| 30-40 | 0.90a | 0.68b | 0.80a | 0.84a | 0.74a | 0.82a | 0.65a | 0.62a | 0.72a |
| 40-50 | 0.69a | 0.58a | 0.63a | 0.78a | 0.54b | 0.70a | 0.47a | 0.50a | 0.52a |

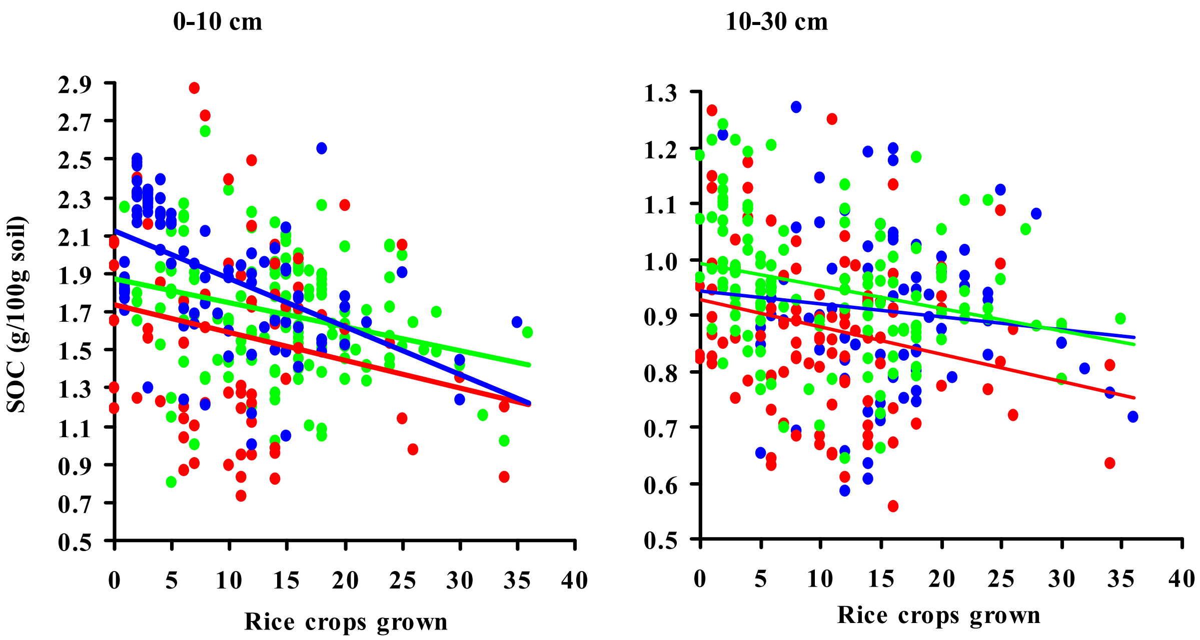


**Figure 1. Effects of rice cropping intensity on SOC concentrations in the surface (0-10 cm) and sub-surface (10-30 cm) layers of the RBE (red), TRBE (blue) and Grey (green) soils rice paddocks.**

**Table 2. Important statistical parameters of SOC, EC, pH, CEC and C:N ratio for the surface and sub-surface soil layers of the common three soils.**

| Statistical parameters | Surface soil (0-10 cm) | | | Sub-surface layer (10-30 cm) | | |
|---|---|---|---|---|---|---|
| | Grey | RBE | TRBE | Grey | RBE | TRBE |
| | Soil organic carbon (g/100g soil) | | | | | |
| Mean | 1.69 | 1.57 | 1.91 | 0.91 | 0.87 | 0.95 |
| Median | 1.66 | 1.54 | 1.91 | 0.91 | 0.86 | 0.95 |
| SD | 0.33 | 0.58 | 0.35 | 0.15 | 0.15 | 0.12 |
| Percent variation | 19.60 | 36.60 | 18.43 | 15.99 | 16.81 | 12.51 |
| | $EC_{1:5}$ (dS/m) | | | | | |
| Mean | 0.17 | 0.11 | 0.15 | 0.21 | 0.14 | 0.18 |
| Median | 0.15 | 0.10 | 0.13 | 0.17 | 0.12 | 0.13 |
| SD | 0.08 | 0.05 | 0.14 | 0.14 | 0.08 | 0.19 |
| Percent variation | 50.54 | 40.90 | 90.79 | 68.94 | 57.04 | 104.23 |
| | $pH_{1:5}$ (0.01M $CaCl_2$) | | | | | |
| Mean | 5.77 | 5.26 | 5.25 | 6.81 | 6.42 | 6.62 |
| Median | 5.76 | 5.09 | 5.25 | 6.85 | 6.26 | 6.48 |
| SD | 0.74 | 0.73 | 0.59 | 0.64 | 0.52 | 0.56 |
| Percent variation | 50.54 | 13.92 | 11.23 | 9.33 | 8.02 | 8.46 |
| | $CEC_{(+)}$ (mol/kg soil) | | | | | |
| Mean | 20.24 | 12.53 | 13.23 | 25.61 | 17.86 | 23.35 |
| Median | 20.33 | 12.50 | 12.00 | 25.99 | 16.95 | 22.45 |
| SD | 7.20 | 4.28 | 5.48 | 6.79 | 4.26 | 6.84 |
| Percent variation | 35.58 | 34.19 | 18.43 | 26.51 | 23.85 | 29.30 |
| | C:N ratio | | | | | |
| Mean | 10.03 | 10.62 | 10.52 | 8.26 | 8.53 | 8.36 |
| Median | 9.76 | 10.83 | 10.30 | 8.06 | 8.16 | 8.30 |
| SD | 1.04 | 1.09 | 1.31 | 0.98 | 1.15 | 1.22 |
| Percent variation | 10.33 | 10.28 | 12.45 | 11.88 | 13.52 | 14.61 |

Variations in SOC concentrations of 30-40 cm and 40-50 cm layers were less remarkable except comparatively higher SOC averages for the TRBE and the grey soils under treeland use. Averages of SOC in the RBE were found to be lower than those for the TRBE and the grey soils under each of the three land uses, most likely due to its coarse textured surface layers considered relatively conducive for rapid decomposition of soil organic materials (Gill 2009).

Distribution of SOC concentrations of the three soils due to the intensity of rice cultivation (Figure 1) shows a notable diversity and variation, most likely due to the integrated effects of different rice farming systems, management practices, soil types, past and present history of land use of sampled paddocks. A consistent trend of decreasing SOC with increased rice cropping in the three soils is very clear. Notwithstanding this observation, average SOC concentrations in RBE paddocks are lower than those of the TRBE and grey soils (Table 2). This clearly demonstrates similarity to observations made in SOC data (Table 1) on land use effects. The differences in the sub-surface layer of the three soil types were comparatively less marked. Data (Table 2) on average EC of different paddocks indicate no major differences in salinity of both the surface and sub-surface layers of the three soils. All the paddocks were tested non-saline and are attributed to the leaching caused by flooded conditions for rice cropping. The soil acidity as measured by pH indicated (Table 2) that surface layer of the three soils are considerably more acidic than their sub-surface layer. Both the layers of the grey soils were less acidic than those of the RBE and the TRBE soils.

Average CEC of both the surface and sub-surface layers of the grey soil rice paddocks was significantly more than those with the RBE and the TRBE. However, CEC of sub-surface soil was more than the surface soil layer in all of the three soils. This confirms relatively higher clay contents in surface layer of the grey soil rice paddocks than those of the RBE and the TRBE. Similar was the observation for all of the three soils as CEC of deeper (10-30 cm) soil layer was greater than their surface (0-10 cm) soil layer due to its greater clay contents. Data on mean and median C:N ratios of both the surface and sub-surface layers did not differ much due to different soils. But the mean and median of sub-soil layer for each of the three soils were about 20 per cent narrower than the surface layer. Variation between the mean and median values of different soil parameters (Table 2) was not significant indicating integrity and normal distribution of experimental data.

## Conclusion

The SOC concentrations showed gradual decline with increased intensity of rice cultivation. Pasture based rice paddocks were having more SOC than those where rice is grown in rotation with winter cereals during the recent past. Rice paddocks with the TRBE and the grey soils had significantly more SOC in the surface (0-10 cm) layer than those of the RBE. This difference was not observed in sub surface layers. This was also true in a parallel investigation on the impact of different land uses on SOC concentrations. Regardless of soil types, sampled rice paddocks were non-saline. The grey soil paddocks were comparatively less acidic than those of the TRBE and the RBE. The surface layer CEC of the grey soil paddocks was significantly more than those of the TRBE and the RBE paddocks. The sub-surface layer CEC of all the three soils was increased significantly. The C:N ratios of the three soils were almost similar but sub-surface C:N ratios relatively narrower than their surface soils counterparts. Results of this investigation indicate the presence of a diverse potential for developing management practices suitable for sustaining fertility and productivity of different soil rice paddocks and increasing productive performance of important agricultural inputs.

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